The Effect of a Reduction in Leading Causes of Death: Potential Gains in Life Expectancy

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Abstract: The potential gains in total expectation of life and in the working life ages among the United States population are examined when the three leading causes of death are totally or partially eliminated. The impressive gains theoretically achieved by total elimination do not hold up under the more realistic assumption of partial elimination or reduction. The number of years gained by a new-born child, with a 30 per cent reduction in major cardiovascular diseases would be 1.98 years, for malignant neoplasms 0.71 years, and for motor vehicle accidents 0.21 years. Application of the same reduction to the working ages, 15 to 70 years, results in a gain of 0.43, 0.26, and 0.14 years, respectively for the three leading causes of death. Even with a scientific break-through in combating these causes of death, it appears that future gains in life expectancies for the working ages will not be spectacular. The implication of the results in relation to the current debate on the national health care policy is noted. (Am. J. Public Health 68:966–971, 1978.)

Introduction

Mortality levels are determined by the complicated interplay of a variety of sociocultural, personal, biological, and medical factors. In the transition from high to low mortality, the relative importance of different causes of death has been altered. Eradication of certain diseases has resulted in an increase of other diseases. The discovery of the bacterial origin of communicable diseases and the birth of a public health movement in the previous century made possible preventive action against the more common and virulent infections. At that time, it was realistic to hope for total eradication of certain infectious diseases.

The trend toward the substantial reductions in mortality started in the previous century has slowed down since 1950. Today when chronic diseases play a major role in mortality, a more realistic goal—especially in terms of planning for health resources—is the reduction rather than elimination of a cause of death. This type of analysis is of special interest not only to public health workers but also to the general public in view of the recent decline in mortality from certain causes. Between 1970 and 1975, for example, the decline in the age-adjusted death rate was 13.7 per cent for major cardiovascular diseases, and 24.8 per cent for motor vehicle accidents.[1]

The contribution of a specific cause of death to general mortality is often measured as the difference between the expectations of life before and after the complete elimination of that cause.[2,3] This approach is not well suited to assessing the effect of marginal mortality improvements. This paper examines potential gains in life expectancies when certain causes of death are partially eliminated, based on the mortality situation in the United States for 1969-71. It seeks to ascertain what potential gains in longevity might be reasonably achieved through efforts to reduce mortality due to major cardiovascular diseases (CVD), malignant neoplasms (MN), and motor vehicle accidents (MVA); a similar approach has recently been reported by Keyfitz.[4] In addition the study seeks to determine how much of these potential gains can be expected during the total life span as well as the normal working lifetime (ages 15-70); this notion is similar to the idea of "partial life expectancies,"[5] and more relevant to discussions of the economic costs of diseases.

Materials and Methods

The basic data sources for this study are the U.S. Census of Population[6] and the deaths for the three-year period 1969-71[7-9] as compiled by the National Center for Health Statistics. In accordance with standard practice, death for which age was not stated have been allocated proportionately among the various age groups for the study. Minor adjustments of population have been made on ages 80 years old.* The causes of death for the three-year period were

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*Appendix B of the 1970 Census of Population states: "the number of persons shown as 100 years old and over is overstated" and "available evidence suggests that the true number of persons 100 years old and over in the United States does not exceed several thousand."[6] The persons for ages 100 years old and over in this study are estimated from the United States life tables[10] and the excess is allocated back to ages 80 to 99.

TABLE 1—Expectation of Life ($\hat{e}_i$) at Various Ages for the Total Population after CVD, MN, and MVA are Completely Eliminated: United States, 1967–71

Exact Age (in years)	Life Expectancy without Elimination	Elimination of CVD $\hat{e}_i$	CVD gain	MN $\hat{e}_i$	MN gain	MVA $\hat{e}_i$	MVA gain
0	70.81	83.17	12.36	73.33	2.52	71.51	0.70
1	71.29	83.89	12.60	73.85	2.56	72.00	0.71
5	67.53	80.16	12.63	70.08	2.55	68.21	0.68
10	62.67	75.32	12.65	65.20	2.53	63.31	0.64
15	57.79	70.46	12.67	60.31	2.52	58.41	0.62
20	53.10	65.83	12.73	55.61	2.51	53.59	0.49
25	48.47	61.28	12.81	50.98	2.51	48.84	0.37
30	43.81	56.67	12.86	46.30	2.49	44.10	0.29
35	39.17	52.08	12.91	41.64	2.47	39.40	0.23
40	34.62	47.55	12.93	37.04	2.42	34.81	0.19
45	30.23	43.14	12.91	32.56	2.33	30.38	0.15
50	26.04	38.88	12.84	28.23	2.19	26.16	0.12
55	22.10	34.82	12.72	24.08	1.98	22.19	0.09
60	18.47	31.02	12.55	20.18	1.71	18.54	0.07
65	15.14	27.46	12.32	16.55	1.41	15.19	0.05
70	12.14	24.19	12.05	13.25	1.11	12.18	0.04
75	9.50	21.19	11.69	10.31	0.81	9.53	0.03
80	7.32	18.61	11.29	7.88	0.56	7.34	0.02
85	5.61	16.40	10.79	5.97	0.36	5.62	0.01
90	4.54	14.75	10.21	4.76	0.22	4.55	0.01
95	4.16	13.47	9.31	4.29	0.13	4.16	0.00
100	2.84	11.38	8.54	2.93	0.09	2.84	0.00

classified according to the Eighth Revision of International Classification of Diseases.[11] The ICD codes for the three causes examined in this study are CVD (390-448), MN (140-209) and MVA (E810-E823).

Enumerated population figures (as of April 1, 1970) were used without adjusting to the midyear and were not adjusted for underenumeration. As far as the present study is concerned, the effects of underenumeration in the census and underregistration in vital statistics are believed to be canceled out to a large extent.**

The basic methodology employed is the construction of life tables. While several different techniques have been proposed in the literature, this study uses Chiang's technique[14] which seems to be operationally more convenient in converting the age specific death rate to the probability of dying. This life table serves as the basis on which the potential gains in life expectancies are evaluated when a certain cause was to be both reduced and completely eliminated.

The life table has only one mode of decrement, which is "death". It is possible to divide the deaths in the general life table into components according to specified causes of death. The result is called a multiple-decrement life table. The multiple-decrement table assumes that a population of individuals is subject to a number of mutually exclusive causes of death which are operating simultaneously. Associated with this multiple-decrement table is the cause-detected table which is constructed by eliminating or reducing a specific cause of death. The method of constructing the multiple-decrement table and the cause-deleted table with partial elimination used in this study is taken from Chiang.[15] The assumption that individuals are subjected to independent competing risks of death may not be realistic, since some causes of death may be dependent and the exact nature of the dependence unknown. However, Chiang's methods provide an adequate approximation for small reduction in a given cause of death.

A slight modification of the formula for net probability of death has been made to allow for a reduction in a cause of death rather than a complete elimination of the cause. More detailed methodology and related issues are discussed elsewhere.[16] The modified net probability is given by the following formula (see Appendix A for derivation):

$$\hat{q}_{i\cdot k}(\pi_{ik}) = 1 - \hat{p}_i^{(D_i - \pi_{ik}D_{ik})/D_i}$$

where $k = 1, 2, \cdots r$,
$\hat{p}_i$ is the probability of surviving age interval (x_i, x_{i+1})
D_i is the total number of deaths of age interval (x_i, x_{i+1})
π_{ik} is the "improvement factor," $0 \leq \pi_{ik} \leq 1$, and
D_{ik} is the number of deaths from cause k in age interval (x_i, x_{i+1}).

The "improvement factor" allows for partial elimination of risk k in age group i. The number of years gained in

**In 1970, for instance, the net census underenumeration for the total population of the United States was estimated to be 1 to 3 per cent and the underenumeration was somewhat greater for nonwhites than for whites.[12] The underregistration of deaths in the United States was estimated to be about 1 per cent in 1967,[13] with more underregistration probable for nonwhites than for whites.

TABLE 2—Added Years of Life at Birth by Reducing CVD, MN, MVA: United States, 1969–71

Causes of Death and Color/Sex Group	Per Cent of Elimination					
	10	20	30	50	70	100
Major Cardiovascular Diseases						
Total Population	0.60	1.26	1.98	3.70	6.01	12.35
White Males	0.59	1.22	1.92	3.56	5.70	11.10
White Females	0.56	1.17	1.85	3.50	5.80	12.81
Nonwhite Males	0.60	1.26	1.98	3.66	5.80	10.74
Nonwhite Females	0.76	1.59	2.51	4.72	7.69	15.66
Malignant Neoplasms						
Total Population	0.23	0.47	0.71	1.20	1.71	2.51
White Males	0.22	0.44	0.66	1.12	1.60	2.35
White Females	0.24	0.49	0.74	1.25	1.78	2.60
Nonwhite Males	0.22	0.44	0.67	1.15	1.65	2.44
Nonwhite Females	0.23	0.47	0.71	1.20	1.71	2.50
Motor Vehicle Accidents						
Total Population	0.07	0.14	0.21	0.35	0.49	0.70
White Males	0.09	0.19	0.28	0.47	0.66	0.94
White Females	0.04	0.08	0.13	0.21	0.29	0.42
Nonwhite Males	0.10	0.19	0.29	0.48	0.68	0.98
Nonwhite Females	0.04	0.07	0.11	0.19	0.26	0.38

life expectancy at birth is calculated by subtracting the life expectancy of the life table from that in the corresponding multiple-decrement table with partial or complete elimination. The added years of life for two sets of working ages are those added years a 15-year-old can expect to live before reaching the end of the working range at age 65 and 70.

Elimination of Selected Risks of Death

The importance of the various causes of death is measured by the gain in life expectancy when a specified cause of death is eliminated. Following the conventional approach, life tables were constructed, completely eliminating CVD, MN, and MVA independently from one another. The results are shown in Table 1 for the total U.S. population. These are consistent with the published statistics, although slightly different methods were used.[2] The potential gains in life expectancy among all U.S. population by the complete elimination of the CVD are: 12.4 years at age 0, 12.9 years at age 40, and 12.1 years at age 70. If it were possible to eliminate MN as a cause of death, the average length of life among Americans, according to mortality conditions in 1969–71, would be increased by 2.5 years at birth, 2.4 years at age 40, and 1.1 years at age 70. The human life wasted by MVA among Americans is estimated to be 0.7 years at birth, 0.2 years at age 40, and 0.04 years at age 70.

These figures are highly improbable since it is unlikely that deaths from CVD, MN, and MVA will be completely eliminated in the foreseeable future. If progress occurs, it is likely to be gradual rather than sudden. Thus a more realistic examination of potential gains in life expectancies would be that based on estimates derived from partial rather than total elimination of these causes of death.

Reduction in Selected Risks of Death

The results of these partial eliminations are presented in Table 2 for the four color/sex groups. It is evident that nonwhite females would have the largest gains if CVD were to be reduced or completely eliminated. This striking gain is a reflection of the fact that proportionately more nonwhite females are dying from these causes than other groups.* A sex differential for whites is less pronounced:
If CVD were reduced by 70 per cent or more, the gains for white females are slightly larger than for white males, while for reductions less than 70 per cent the gains are about the same for both sexes. For MN there is no appreciable difference in years of potential gain among color/sex groups. On the other hand, sex differentials in added years of life at birth are clearly achieved by the partial or complete elimination of MVA.

Table 2 indicates that the added years of life gained by 50 per cent elimination are about one-half the years gained by 100 per cent elimination for MN and MVA, but that the gains by 50 per cent elimination of the CVD (3.7 years) are less than one-third of the gains expected by 100 per cent elimination (12.4 years). These relationships for the three causes of death for the four color/sex groups are graphically illustrated in Figures 1, 2, and 3. When the mortality rate from the cause of death being eliminated is relatively small, the increase in expectation of life is approximately a linear function of the proportion eliminated. This linearity can be shown mathematically (see Appendix B). For the cause of death which is relatively large, the linear relationship no longer holds.

*This is shown in Table 4 which will be discussed later.

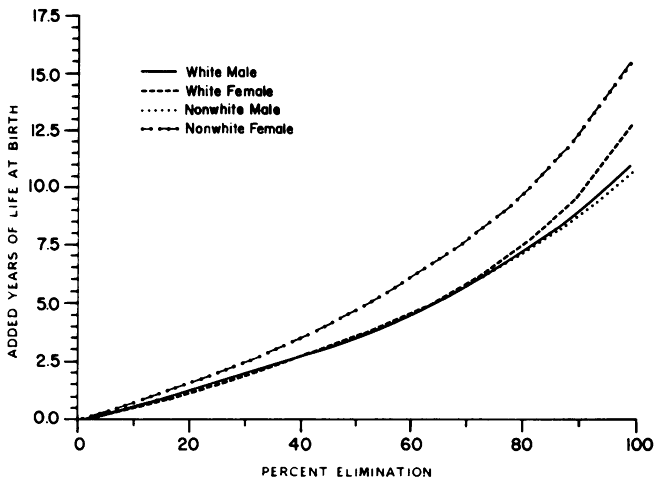

FIGURE 1—The Relationship between Per Cent Elimination of CVD and Added Years of Life at Birth: United States, 1969–1971

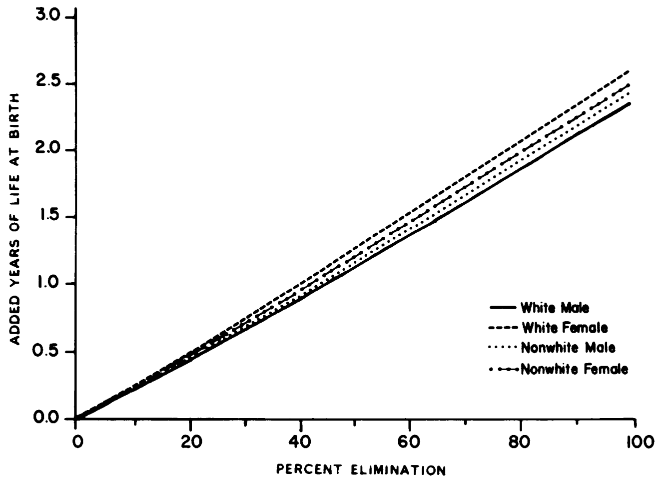

FIGURE 2—The Relationship between Per Cent Elimination of MN and Added Years of Life at Birth: United States, 1969–1971

Potential Gains for Working Ages

As argued earlier, the restriction of analysis to the working ages would produce more realistic results not only for discussion of the economic costs of disease but also for avoiding certain problems resulting from the quality of data for older ages. The potential gains expected for working ages by both the partial and complete elimination of the three causes of death are shown in Table 3. Even with 100 per cent elimination of the CVD, Americans would gain less than one year for working ages from 15 to 65 years and one and one-half years for working ages from 15 to 70 years. The data allow the impact of the recently extended retirement age to be examined by comparing the years of life gain from the two sets of working ages. The potential gain expected for working ages (15–70) by elimination of CVD represents only 12 per cent of the expected gain for the entire life span, as compared with 36 per cent for MN and 66 per cent for MVA.

TABLE 3—Added Years of Life for Working Ages by Reducing CVD, MN, and MVA: United States, 1969–71

Cause of Death and Color/Sex Group	Working Ages: Between Ages 15 and 65 Years, Per Cent Elimination						Between Ages 15 and 70 Years, Per Cent Elimination					
	10	20	30	50	70	100	10	20	30	50	70	100
Major Cardiovascular Diseases												
Total Population	0.09	0.18	0.27	0.45	0.63	0.91	0.14	0.29	0.43	0.73	1.04	1.51
White Males	0.11	0.23	0.35	0.58	0.83	1.20	0.18	0.37	0.56	0.95	1.35	1.98
White Females	0.04	0.08	0.13	0.22	0.31	0.45	0.08	0.16	0.23	0.39	0.55	0.79
Nonwhite Males	0.16	0.32	0.49	0.83	1.17	1.71	0.23	0.47	0.71	1.20	1.72	2.54
Nonwhite Females	0.12	0.25	0.37	0.63	0.89	1.29	0.19	0.38	0.57	0.96	1.37	2.00
Malignant Neoplasms												
Total Population	0.06	0.12	0.17	0.29	0.41	0.59	0.09	0.17	0.26	0.44	0.62	0.89
White Males	0.06	0.11	0.17	0.28	0.39	0.56	0.09	0.17	0.26	0.43	0.61	0.87
White Females	0.06	0.12	0.17	0.29	0.41	0.59	0.09	0.17	0.26	0.44	0.61	0.88
Nonwhite Males	0.07	0.13	0.20	0.33	0.47	0.68	0.10	0.19	0.29	0.49	0.69	1.00
Nonwhite Females	0.07	0.13	0.20	0.34	0.47	0.68	0.09	0.19	0.29	0.48	0.68	0.97
Motor Vehicle Accidents												
Total Population	0.04	0.08	0.12	0.20	0.28	0.40	0.05	0.09	0.14	0.23	0.32	0.46
White Males	0.06	0.12	0.18	0.30	0.42	0.60	0.07	0.13	0.20	0.34	0.47	0.68
White Females	0.02	0.04	0.06	0.10	0.14	0.19	0.02	0.05	0.07	0.11	0.16	0.23
Nonwhite Males	0.06	0.12	0.18	0.31	0.43	0.62	0.07	0.14	0.21	0.34	0.48	0.70
Nonwhite Females	0.02	0.03	0.05	0.09	0.12	0.18	0.02	0.04	0.06	0.10	0.14	0.20

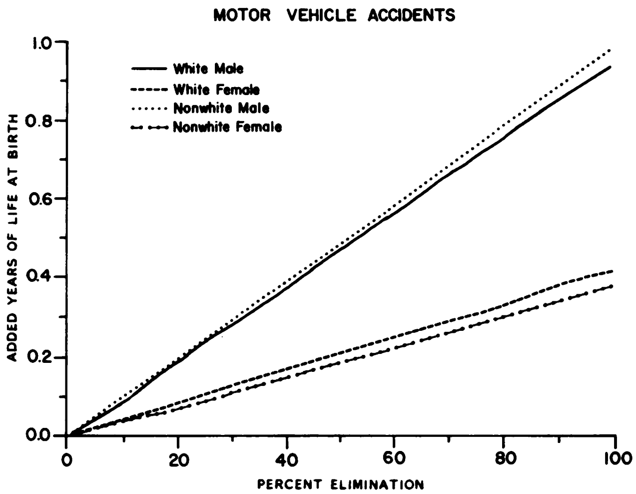

FIGURE 3—The Relationship between Per Cent Elimination of MVA and Added Years of Life at Birth: United States, 1969–1971

TABLE 4—Proportion of Deaths Due to CVD in the Older Age Groups: United States, 1969–71

Age Group (in years)	Total Population	White		Nonwhite	
		Males	Females	Males	Females
30-35	0.23	0.25	0.18	0.22	0.26
35-40	0.31	0.36	0.21	0.30	0.32
40-45	0.37	0.44	0.25	0.36	0.38
45-50	0.42	0.49	0.30	0.42	0.43
50-55	0.46	0.51	0.36	0.46	0.47
55-60	0.50	0.53	0.44	0.49	0.54
60-65	0.55	0.56	0.53	0.53	0.59
65-70	0.60	0.59	0.61	0.56	0.63
70-75	0.64	0.62	0.67	0.58	0.67
75-80	0.69	0.66	0.72	0.61	0.69
80-85	0.73	0.70	0.75	0.64	0.72
85-90	0.76	0.73	0.78	0.66	0.74
90-95	0.77	0.74	0.79	0.68	0.75
95+	0.67	0.59	0.74	0.54	0.66

This is a result of the increasing proportion of deaths due to cardiovascular causes in the older age groups as shown in Table 4. As a result, when working ages are considered, the relative importance of these three causes changes.

The striking gains observed for nonwhite females by the elimination of CVD when the entire lifetime was considered are no longer evident when the working lifetime is considered. This suggests that a large portion of CVD deaths for nonwhite females were in the later stages of life. Among males, MVA and MN are of about equal importance as far as working ages are concerned. A 30 per cent reduction of CVD would add only about twice as much working life as the other two causes of death among white males.

Discussion

This study demonstrates the usefulness of multiple-decrement life tables as a tool to examine potential gains by reducing as well as eliminating a particular disease or condition as a cause of death. Gains of life expectancy due to complete elimination of a disease are based on the implicit assumption that the years lived at any age are of equal value. However, in terms of the economic costs and benefits, this assumption may not be valid, and years of life gained for working ages may be a more relevant mortality indicator. When considering added years of life expectancy for the normal working lifetime, the potential gains are small. With a 50 per cent reduction in mortality due to CVD, the potential gain in the working life ages 15 to 70 years is less than three-fourths of one year and a significant change occurs in the relative impact of CVD, MN and MVA. The relative importance of MVA as a cause of death in a working lifetime is markedly increased in contrast to its minor importance when an entire lifetime is considered. Hence from an economic standpoint, programs designed to prevent motor vehicle accidents should be given high priority.

It is assumed in the foregoing analysis that there are no interdependencies among the causes of deaths. As previously mentioned, this assumption may not be realistic, for a given disease may well render its victim more susceptible to certain other diseases. Conversely, it is even possible that the occurrence of some diseases may leave an individual with increased resistance to some other diseases. Nevertheless, the assumption of independence can hardly be avoided until more is known about the exact nature of the interdependency among various causes of death.

In spite of the known limitations of multiple-decrement life table analysis, the findings from this study have implications for practical decision making in setting up health goals, allocating resources, and evaluating health programs. The current debate on health care policy seems to point to the inevitability of choice—individually and collectively—among competing human wants and calls for intelligent decisions based on careful evaluation of various alternatives. The examination of potential gains in life expectancies will assist in this process. Further studies of this nature seem indicated.

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APPENDIX A

$$q_{i\cdot k}(\pi_{ik}) = 1 - \exp\left\{-\int_{x_i}^{x_i+1}[\mu(t) - \pi_{ik}\mu(t;k)]dt\right\}$$

$$= 1 - \exp\left\{-\int_{x_i}^{x_i+1}[\mu(t) - \pi_{ik}C_{ik}\mu(t)]dt\right\} \quad \text{where}$$

$$C_{ik} = \frac{\mu(t;k)}{\mu(t)}$$

$$= 1 - \exp\left\{-\int_{x_i}^{x_i+1}[1 - \pi_{ik}C_{ik}]\mu(t)dt\right\}$$

$$= 1 - p_i^{[1-\pi_{ik}C_{ik}]}$$

$$= 1 - p_i^{[\mu(t)-\pi_{ik}\mu(t;k)]/\mu(t)} \quad \text{or}$$

$$q_{i\cdot k}(\pi_{ik}) = 1 - p_i^{[q_i-\pi_{ik}Q_{ik}]/q_i}.$$

Substituting $\hat{q}_i = D_i/N_i$ and $\hat{Q}_{ik} = D_{ik}/N_i$, where N_i is the number of individuals alive at exact age X_i among whom D_i deaths occur in the interval (x_i, x_{i+1}) then $\hat{q}_{i\cdot k}(\pi_{ik}) = 1 - \hat{p}_i^{(D_i-\pi_{ik}D_{ik})/D_i}$.

APPENDIX B

The expectation of life at birth can be written as the integral of the survivorship function as follows

$$e_o = \int_o^\infty F(t)dt$$

where t denotes the survival time, $F(t) = \exp\left[-\int_o^t \mu(\tau)d\tau\right]$ and $\mu(t) = \mu(t;1) + \cdots + \mu(t;r)$ is an additive function of the cause specific mortality intensity functions $\mu(t;k)$ for $k = 1, 2, \cdots, r$. If cause R_1 is reduced by a proportion π_1, then

$$e_o(\pi_1) = \int_o^\infty \exp\left\{-\int_o^t[\mu(\tau) - \pi_1\mu(\tau;1)]d\tau\right\}dt.$$

The gain in life expectancy can be expressed in integral form

$$e_o(\pi_1) - e_o = \int_o^\infty \exp\left\{-\int_o^t[\mu(\tau) - \pi_1\mu(\tau;1)]d\tau\right\}dt - \int_o^\infty F(t)dt$$

$$= \int_o^\infty F(t)\left\{\exp\left[\pi_1\int_o^t \mu(\tau;1)d\tau\right] - 1\right\}dt.$$

A convenient approximation to the right hand side of the equation above is obtained by expanding the exponential expression in the integrand i.e.

$$\{\cdot\} = e^{-\pi_1\left[-\int_o^t \mu(\tau;1)d\tau\right]} - 1$$

$$= [1 - q_1(t)]^{-\pi_1} - 1$$

where $q_1(t) = 1 - \exp\left\{-\int_o^t \mu(\tau;1)d\tau\right\}$.

If $\mu(\tau;1)$ is small and correspondingly $q_1(t)$ is small, then $\{\cdot\} \cong \pi_1 q_1(t)$. And the gain in expectation of life becomes

$$e_o(\pi_1) - e_o \cong \pi_1\int_o^\infty F(t)q_1(t)dt$$

At $\pi_1 = 1$, we get $e_o(1) - e_o \cong \int_0^\infty F(t)q_1(t)dt$ and, therefore,

$$e_o(\pi_1) - e_o \cong \pi_1[e_o(1) - e_o].$$

This approximation is quite good as long as $\pi_1\int_o^t \mu(\tau;1)d\tau$ remains small and will slightly over estimate the actual value of $e_o(\pi_1) - e_o$. This shows that the gain in expectation of life associated with a reduction in R_1 by amount π_1 is π_1 times the gain that would be achieved if R_1 were eliminated as a risk of death.